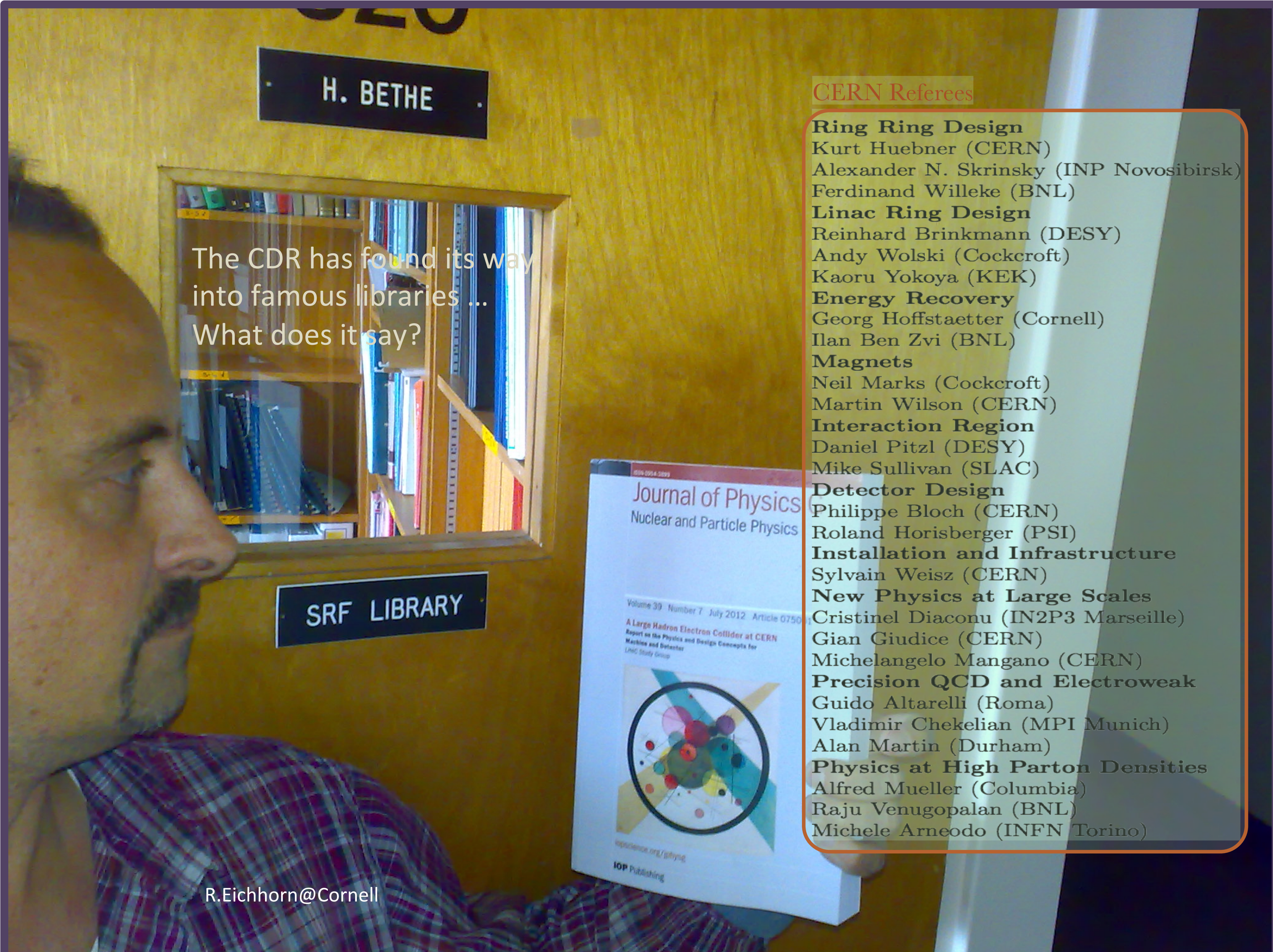
From Chavannes June 2012 to Chavannes January 2014

Max Klein

20.1.2014

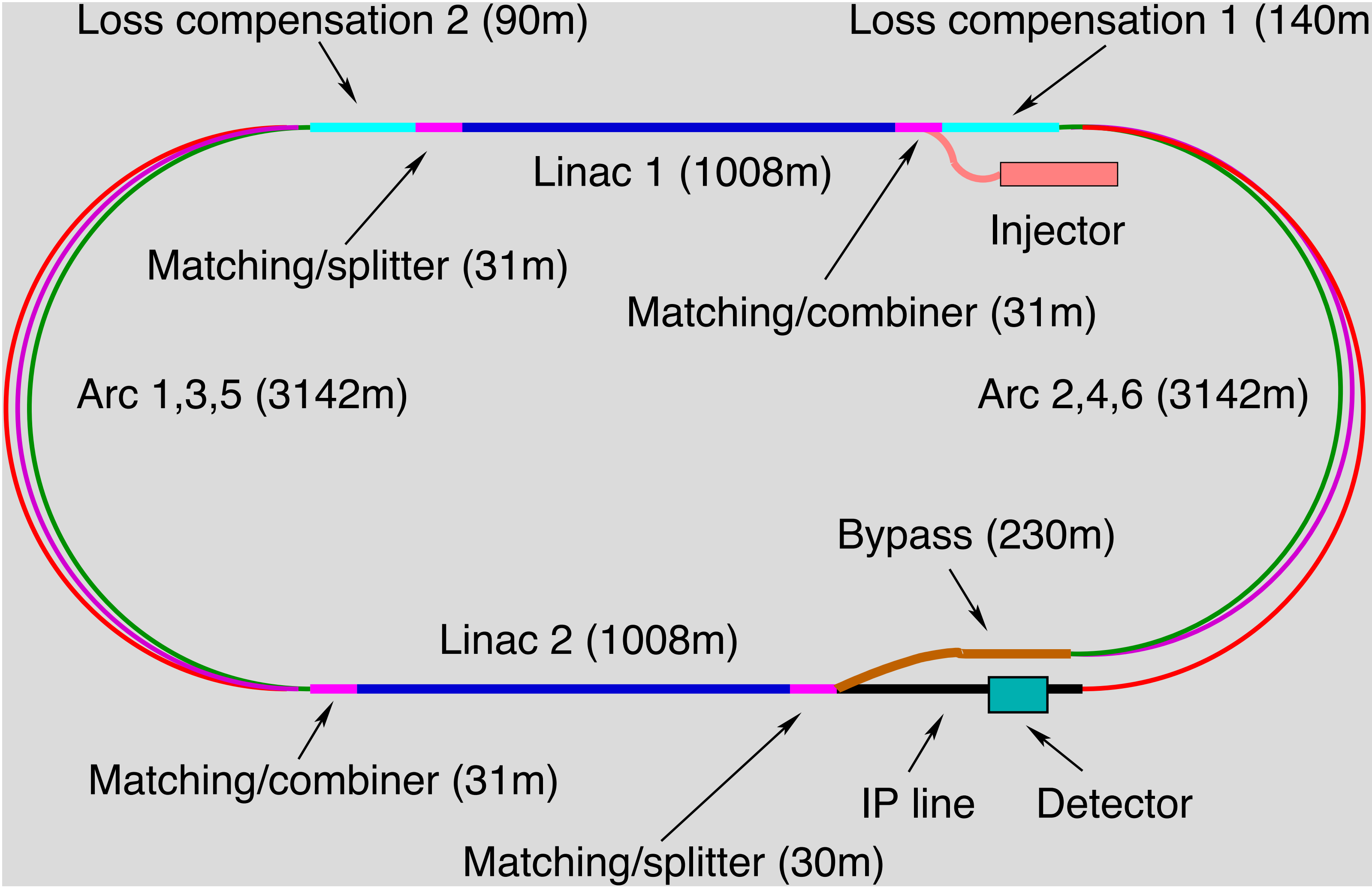


The CDR has found its way into famous libraries ... What does it say?

CERN Referees

Ring Ring Design
Kurt Huebner (CERN)
Alexander N. Skrinsky (INP Novosibirsk)
Ferdinand Willeke (BNL)
Linac Ring Design
Reinhard Brinkmann (DESY)
Andy Wolski (Cockcroft)
Kaoru Yokoya (KEK)
Energy Recovery
Georg Hoffstaetter (Cornell)
Ilan Ben Zvi (BNL)
Magnets
Neil Marks (Cockcroft)
Martin Wilson (CERN)
Interaction Region
Daniel Pitzl (DESY)
Mike Sullivan (SLAC)
Detector Design
Philippe Bloch (CERN)
Roland Horisberger (PSI)
Installation and Infrastructure
Sylvain Weisz (CERN)
New Physics at Large Scales
Cristinel Diaconu (IN2P3 Marseille)
Gian Giudice (CERN)
Michelangelo Mangano (CERN)
Precision QCD and Electroweak
Guido Altarelli (Roma)
Vladimir Chekelian (MPI Munich)
Alan Martin (Durham)
Physics at High Parton Densities
Alfred Mueller (Columbia)
Raju Venugopalan (BNL)
Michele Arneodo (INFN Torino)

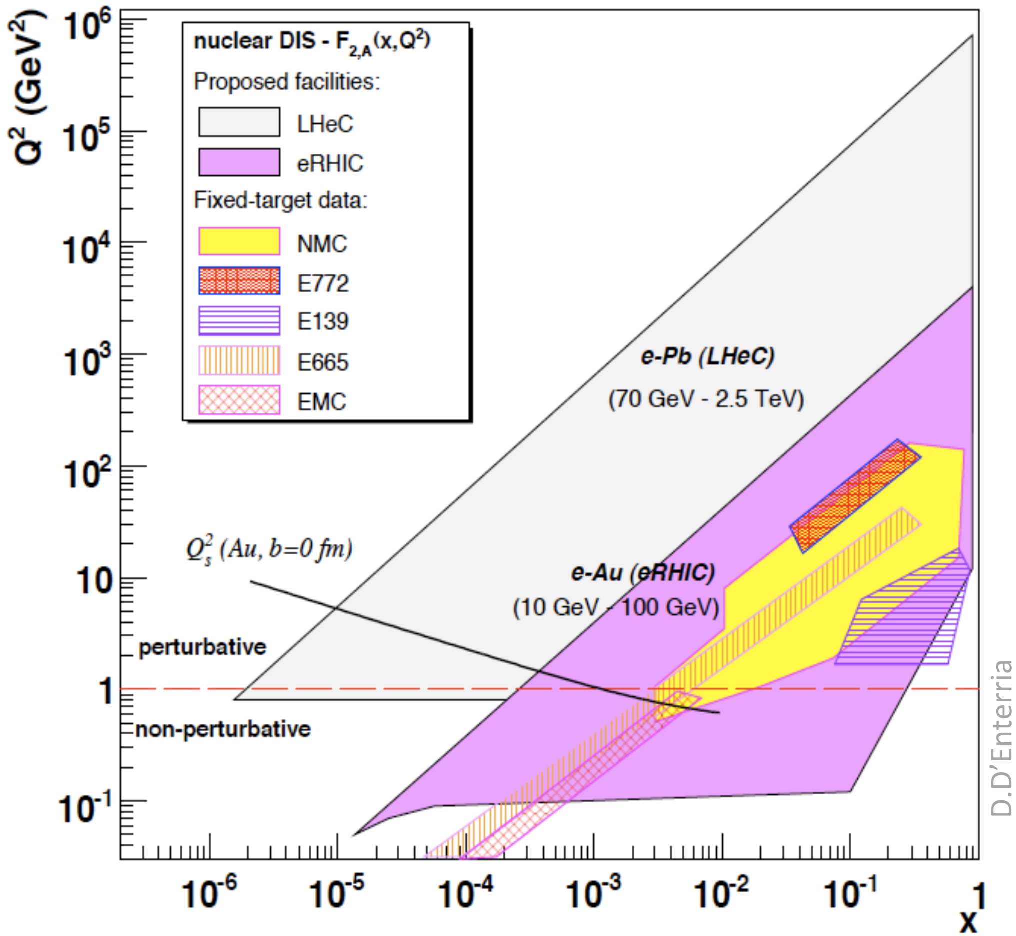
LHC electron beam upgrade



JPhysG:39(2012)075001, arXiv:1206.2913 http://cern.ch/lhec

CDR: default design. 60 GeV. $L=10^{33} cm^{-2} s^{-1}$, P< 100 MW → ERL, synchronous ep/pp

Energy Frontier Electron Ion Collider



LHeC is part of NuPECCs long range plan since 2010
$L_{eN} \sim 10^{32}$ cm^{-2} s^{-1}

Extension of kinematic range in lA by four orders of magnitude will change QCD view on nuclear structure and parton dynamics

May lead to genuine surprises…

- No saturation of xg (x,Q^2) ?
- Small fraction of diffraction ?
- Broken isospin invariance ?
- Flavour dependent shadowing ?

Expect saturation of rise at
$Q^2_s \approx xg\ \alpha_s \approx c\ x^{-\lambda} A^{1/3}$

Precision QCD study of parton dynamics in nuclei
Investigation of high density matter and QGP
Gluon saturation at low x, in DIS region.

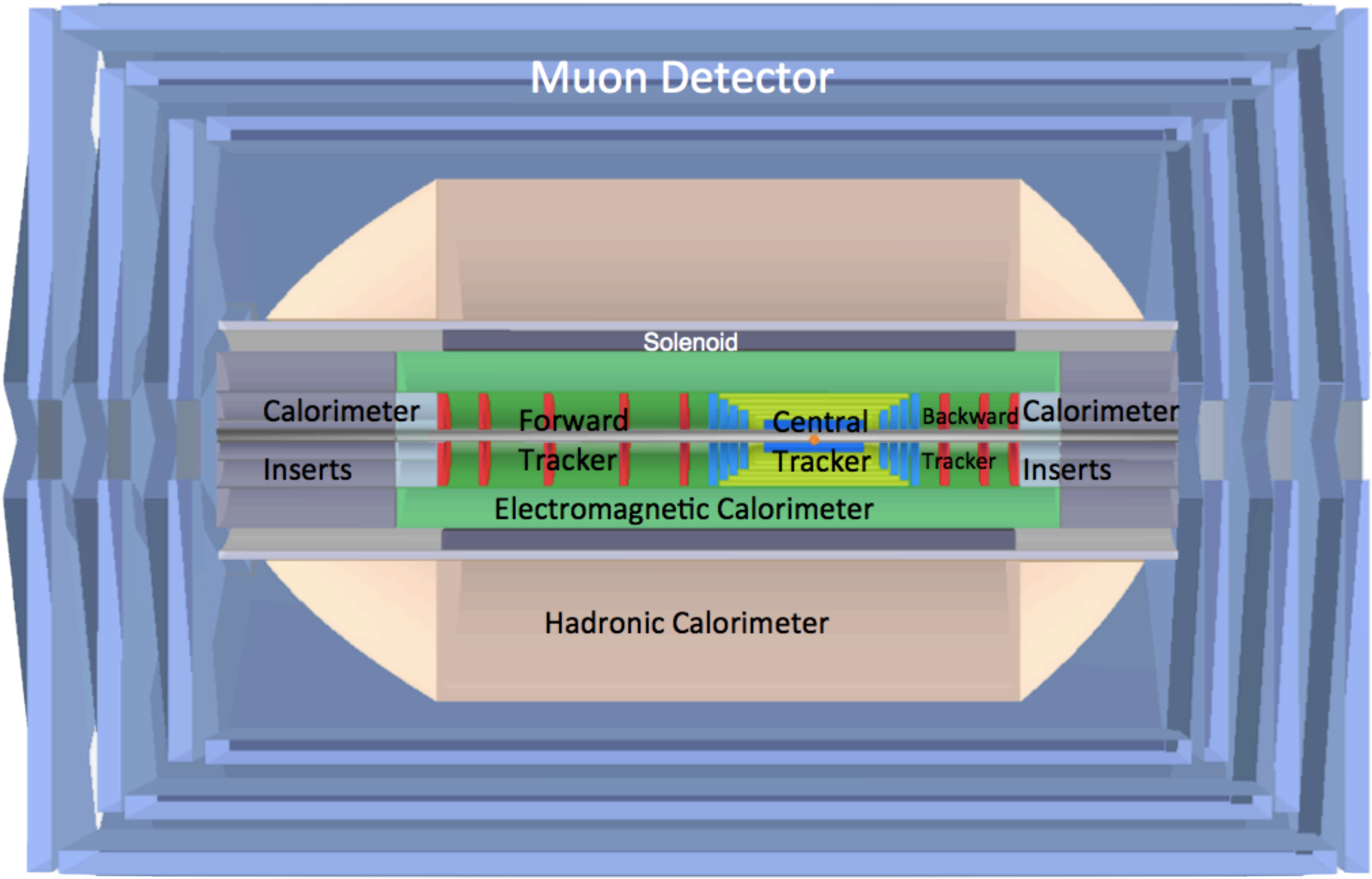
Summary of LHeC Physics [arXiv:1211:4831+5102]

The LHeC represents a new laboratory for exploring a hugely extended region of phase space with an unprecedented high luminosity in high energy DIS. It builds the link to the LHC and a future pure lepton collider, similar to the complementarity between HERA and the Tevatron and LEP, yet with much higher precision in an extended energy range. Its physics is fundamentally new, and it also is complementary especially to the LHC, for which the electron beam is an upgrade. Given the broad range of physics questions, there are various ways to classify these, partially overlapping. An attempt for a schematic overview on the LHeC physics programme as seen from today is presented in Tab. 3. The conquest of new regions of phase space and intensity has often lead to surprises, which tend to be difficult to tabulate.

QCD Discoveries	$\alpha_s < 0.12$, $q_{sea} \neq \overline{q}$, instanton, odderon, low x: (n0) saturation, $\overline{u} \neq \overline{d}$
Higgs	WW and ZZ production, $H \to b\overline{b}$, $H \to 4l$, CP eigenstate
Substructure	electromagnetic quark radius, e^*, ν^*, W?, Z?, top?, H?
New and BSM Physics	leptoquarks, RPV SUSY, Higgs CP, contact interactions, GUT through α_s
Top Quark	top PDF, $xt = x\overline{t}$?, single top in DIS, anomalous top
Relations to LHC	SUSY, high x partons and high mass SUSY, Higgs, LQs, QCD, precision PDFs
Gluon Distribution	saturation, $x \approx 1$, J/ψ, Υ, Pomeron, local spots?, F_L, F_2^c
Precision DIS	$\delta\alpha_s \simeq 0.1\,\%$, $\delta M_c \simeq 3\,\mathrm{MeV}$, $v_{u,d}$, $a_{u,d}$ to $2-3\,\%$, $\sin^2\Theta(\mu)$, F_L, F_2^b
Parton Structure	Proton, Deuteron, Neutron, Ions, Photon
Quark Distributions	valence $10^{-4} \lesssim x \lesssim 1$, light sea, d/u, $s = \overline{s}$?, charm, beauty, top
QCD	N^3LO, factorisation, resummation, emission, AdS/CFT, BFKL evolution
Deuteron	singlet evolution, light sea, hidden colour, neutron, diffraction-shadowing
Heavy Ions	initial QGP, nPDFs, hadronization inside media, black limit, saturation
Modified Partons	PDFs "independent" of fits, unintegrated, generalised, photonic, diffractive
HERA continuation	F_L, xF_3, $F_2^{\gamma Z}$, high x partons, α_s, nuclear structure, ..

Table 3: Schematic overview on key physics topics for investigation with the LHeC.

LHeC Baseline Detector - CDR



Detector option 1 for LR and full acceptance coverage

Forward/backward asymmetry in energy deposited and thus in geometry and technology
Present dimensions: LxD =14x9m^2 [CMS 21 x 15m^2 , ATLAS 45 x 25 m^2]
Taggers at -62m (e),100m (γ,LR), -22.4m (γ,RR), +100m (n), +420m (p)

July 2012

A New Era of Particle Physics

4.7.2012 greeting Melbourne from CERN

“The Higgs: So simple and yet so unnatural” G.Altarelli,arXiv:1308.0545

LHeC presented at Melbourne in various sessions, including a talk (UK) on the Higgs in ep

October 2012

Luminosity

The CDR Luminosity

$$L = \frac{N_e N_p f \gamma_p}{4\pi\varepsilon_p \beta^*}$$

$$N_e = 10^9$$

$$N_p = 1.7 \cdot 10^{11}$$

$$\varepsilon_p = 3.7\mu m$$

$$f = \frac{1}{\Delta} = 40 MHz$$

$$\beta^* = 0.1m$$

$$\Rightarrow L = 10^{33} cm^{-2} s^{-1}$$

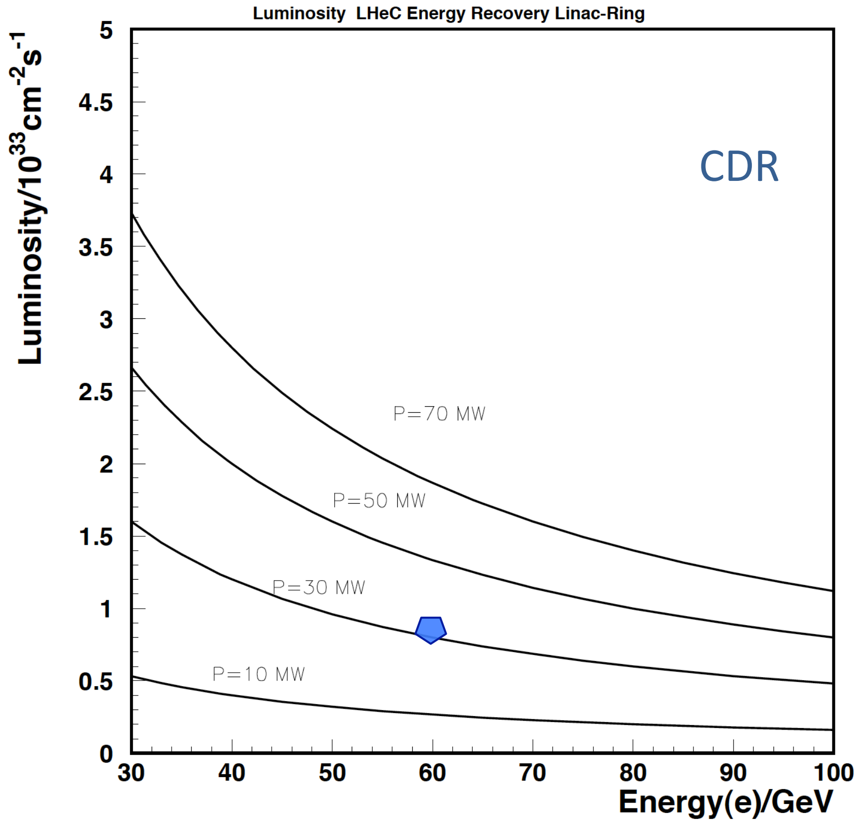
$$I_e = eN_e f = 6.4mA$$

$$I_e = \frac{P}{E_e}$$

$$P = \frac{P_0}{(1-\eta)}, \eta = 0.94$$

$$P_0 = 24MW$$

H*pinch(e^-)*gap-loss ~ 1



Higgs in ep sets scale for luminosity!

… so do searches, high x and special conditions such as positron, deuteron, eA or low energy..

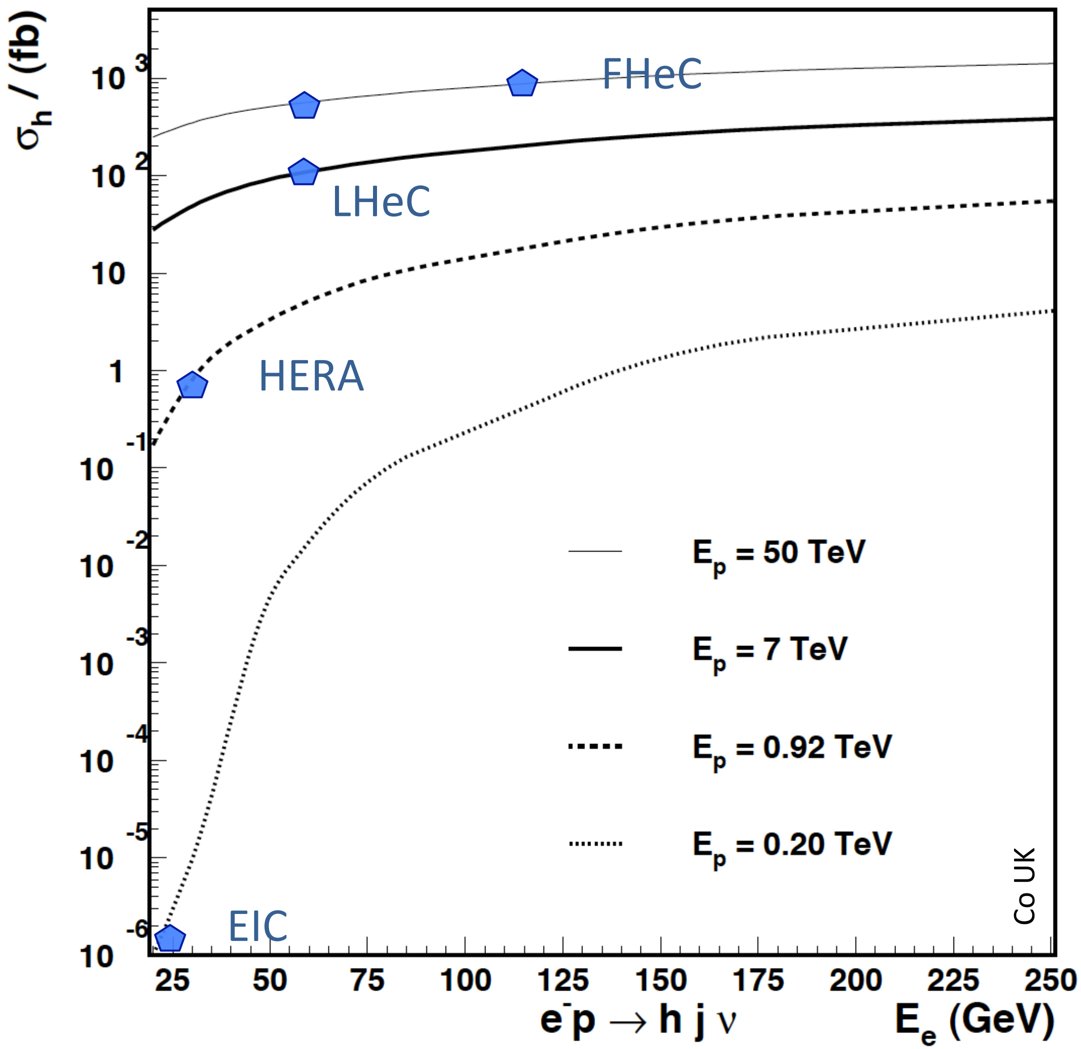
after the Higgs arXiv:1211.5102
2.5 * brightness, 2 * I_e , 0.5 * β*

LHeC Luminosity → 10^{34} cm^{-2} s^{-1}

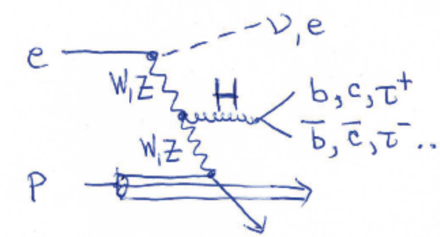
L(E,P) subject of current study: beam-beam, ion gap stability…

Higgs in Deep Inelastic Scattering

R. Godbole PRD 18 (78) 95



Charged current ep: Cross section as large as at TLEP/ILC



LHeC Higgs		CC (e^-p)	NC (e^-p)	CC (e^+p)
Polarisation		-0.8	-0.8	0
Luminosity [ab^{-1}]		1	1	0.1
Cross Section [fb]		196	25	58
Decay	BrFraction	N^H_{CC} e^-p	N^H_{NC} e^-p	N^H_{CC} e^+p
$H \to b\bar{b}$	0.577	113 100	13 900	3 350
$H \to c\bar{c}$	0.029	5 700	700	170
$H \to \tau^+\tau^-$	0.063	12 350	1 600	370
$H \to \mu\mu$	0.00022	50	5	–
$H \to 4l$	0.00013	30	3	–
$H \to 2l2\nu$	0.0106	2 080	250	60
$H \to gg$	0.086	16 850	2 050	500
$H \to WW$	0.215	42 100	5 150	1 250
$H \to ZZ$	0.0264	5 200	600	150
$H \to \gamma\gamma$	0.00228	450	60	15
$H \to Z\gamma$	0.00154	300	40	10

LHeC O(10^5) H from VBF

bb: S/N = 1: coupling to 1%

Under study cc, ττ, ... CP with LHeC detector takes much effort+time

The Question of the next Decade(s)

What is really this Higgs boson that might have been discovered at ~ 125GeV?

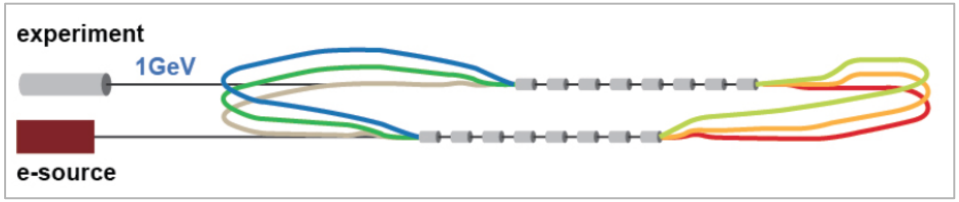
" Higgs = emergency tire of the SM"

Altarelli @ Blois'10

[picture courtesy to Andreas Weiler]

ERL Test Facility at CERN

ERL Workshop at Daresbury: January 2013. f=801.54 MHz, I=10mA, $Q_0 > 2\ 10^{10}$



Need a design a bit more specific than the poster sketch ..

Applications

Development of SuperConducting RF technology at CERN (November 13 – ok)

Operation and experience with S.C energy recovery linac

Injector to LHeC → injector to a future e+/e- machine

Testbed for SC magnets, cables, stacks – in high dose, non-radiative environment

Experiments with **electron beam**: PV at $Q^2 \sim 1\ GeV^2$, proton radius

Experiments with **photon beam**: much higher intensity than ELI-NP

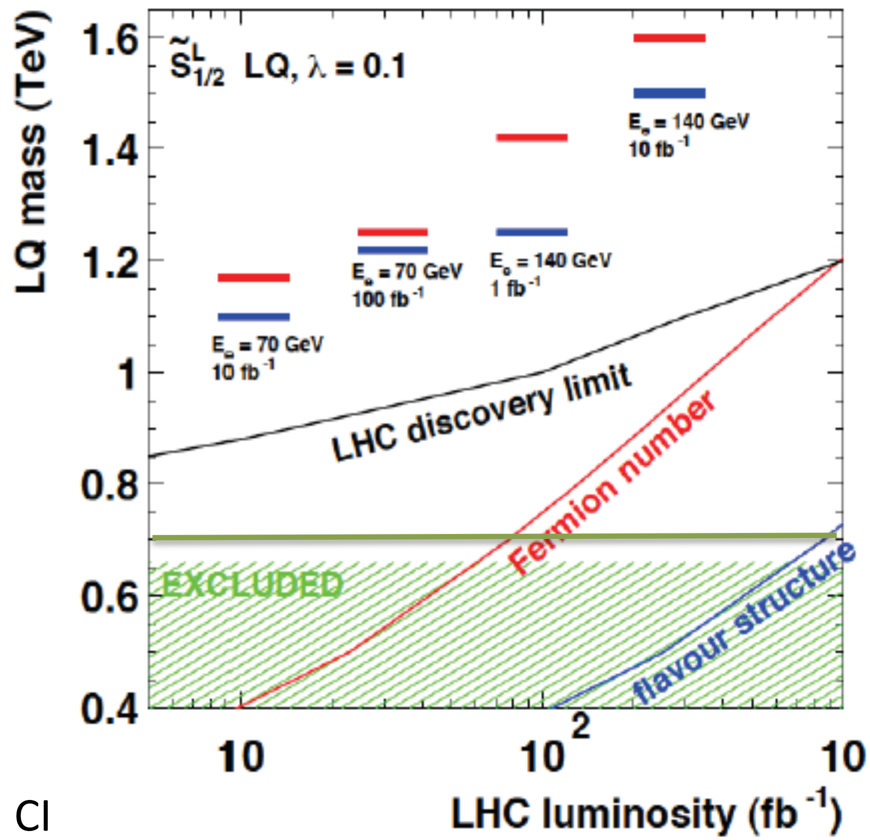
LPCC mini workshop on LHeC 17/18.4.2013 at CERN

Review of CDR
Updates and discussion with LHC

LHeC at LPCC

PDFs –	V.Radescu
Heavy PDFs –	R.Placakyte
Accelerator –	O.Brüning
Higgs –	B. Mellado
BSM LH(e)C –	M.D'Onofrio
QCD at low x –	A.Stasto
eA Physics –	N.Armesto

http://cern.ch/lhec



From CDR 6/12

BSM with LHeC:
RPV SUSY,LQs, r_{quark}, excited leptons, CI

" The LHC is the primary machine to search for physics beyond the SM at the TeV scale.
The role of the LHeC is to complement and possibly resolve the observation of new phenomena…"
LHeC CDR

Possible QCD Developments

AdS/CFT

Instantons

Odderons

Non pQCD

QGP

N^kLO

Resummation

Non-conventional PDFs …

Breaking of Factorisation

Free Quarks

Unconfined Color

New kind of coloured matter

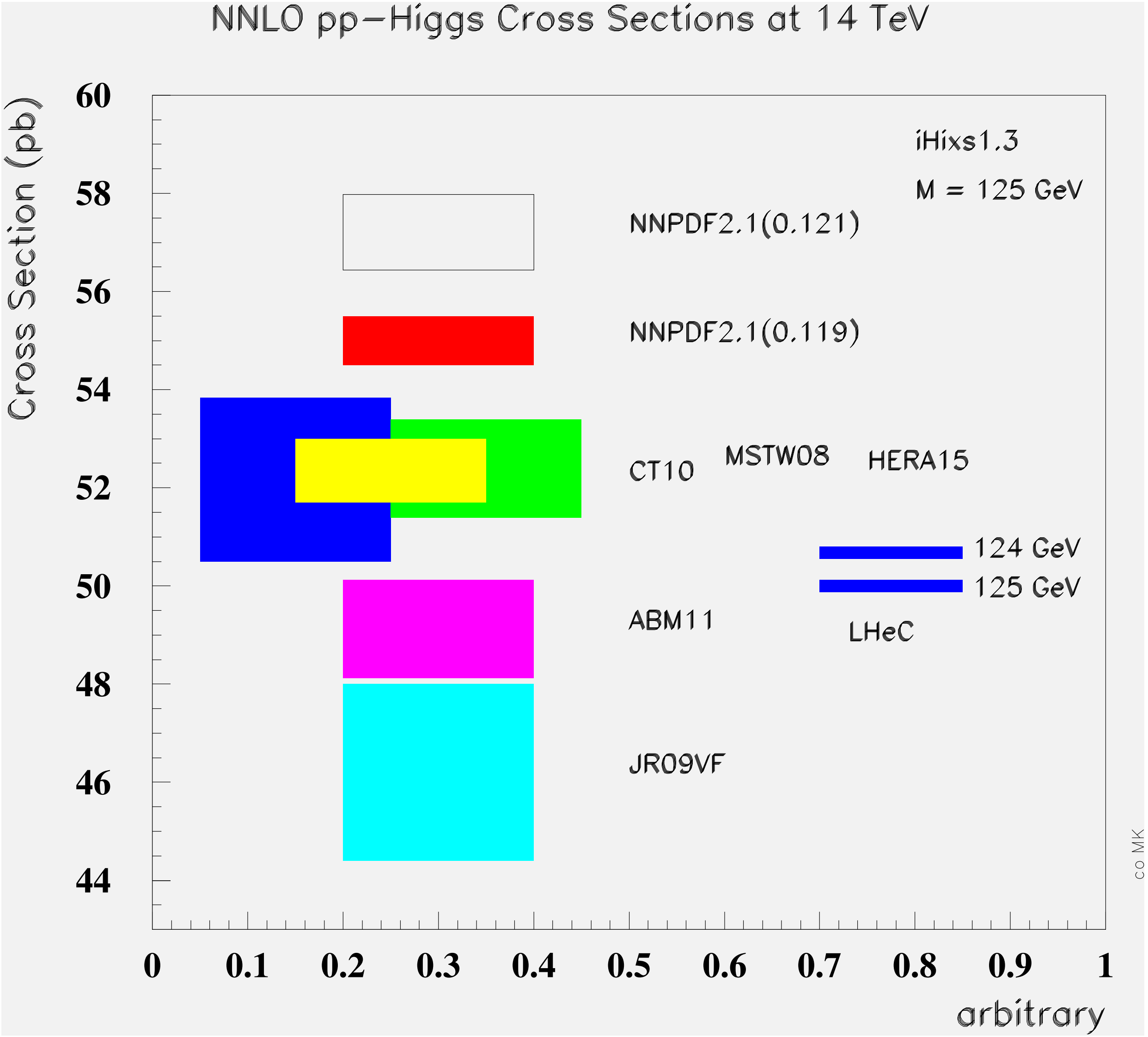
Quark substructure

New symmetry embedding QCD

QCD may break .. (Quigg DIS13)

QCD is the richest part of the Standard Model Gauge Field Theory and will (have to) be developed much further, on its own and as background

Precision for Higgs at the LHC



O.Brüning and M.Klein arXiv:1305.2090, MPLA 2013

LHeC:

Exp uncertainty of predicted H cross section is 0.25% (sys+sta), using LHeC only.

Leads to H mass sensitivity.

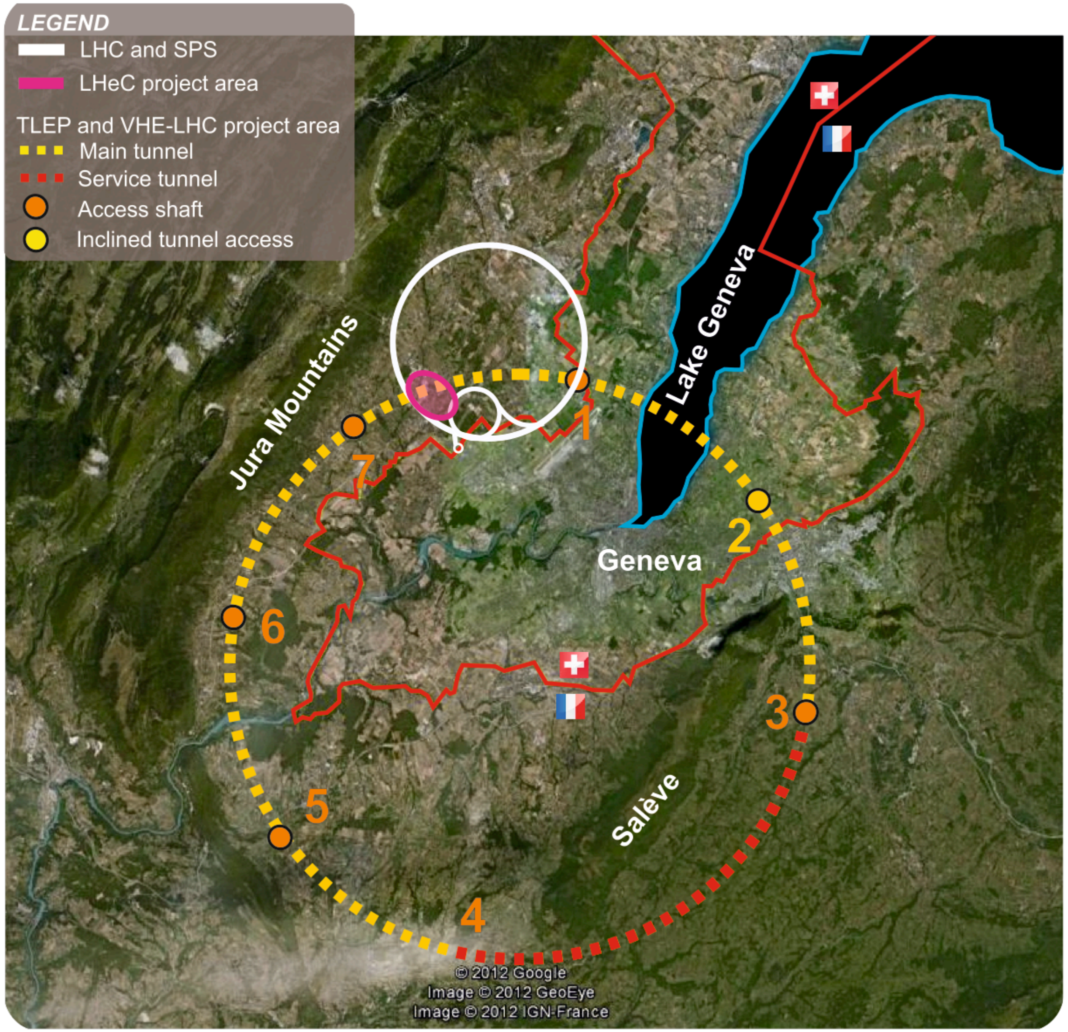
Strong coupling underlying parameter (0.005 → 10%). LHeC: 0.0002 !

Needs N^3LO

HQ treatment important …

May 2013

A tunnel under Lac Leman



The ERL may be connected to the new tunnel for an "FHeC" if that is included in the CE planning.

Important constraint will be injection into the big tunnel. ERL could be injector for "TLEP".

Three phases of FCC project
- exploration 2014
- baseline 2015/16
- consolidation 2017 – CDR

The (very) long term FCC future opens a further dimension also for the LHeC development.

*) "Civil Engineering Feasibility Studies for Future Ring Colliders at CERN", Contributed by O.Brüning, M.Klein, S.Myers, **J.Osborne**, L.Rossi, C.Waaijer, F.Zimmerman to **IPAC13 Shanghai**

Next decades

Rolf Heuer at
Aix Les Bains
1. 10. 2013

Road beyond Standard Model

LHC results vital to guide the way at the energy frontier

At the energy frontier through synergy of

hadron - hadron colliders (LHC, (V)HE-LHC?)

lepton - hadron colliders (LHeC ??)

lepton - lepton colliders (LC (**ILC** or CLIC) ?)

May 2013

title

IPAC13 Shanghai

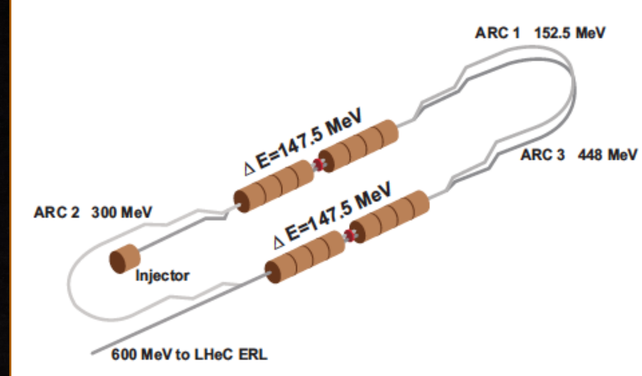


Figure 2: Consequent upgrade to LHeC pre-accelerator. By modifying the machine backleg to include a second full cryomodule, the recirculator can deliver higher beam energy of 600 MeV.

CERN-Jlab, A.Valloni et al

Various contributions to IPAC13 and one invited talk on LHeC

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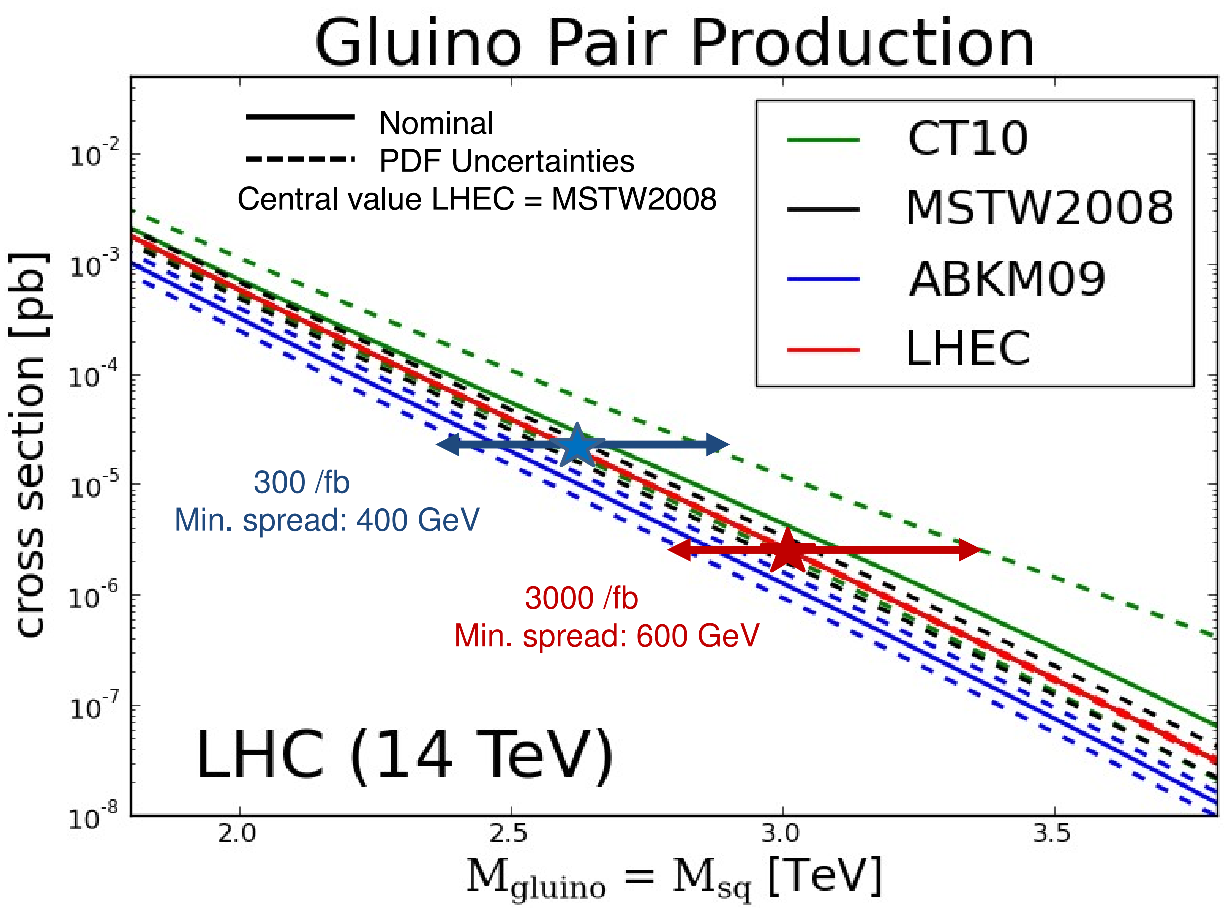
July 2013

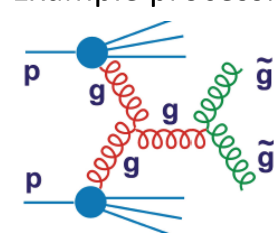
EPS Stockholm (H, Searches, eA, Det, ACC)



The gain in reach with high luminosity at the HL LHC is basically similar to the uncertainty at high mass due to high x PDFs

→ LHeC + High Lumi for optimum use of luminosity upgrade.

Example process:



LHeC BSM poster at EPS13 M.D'Onofrio et al. see also arXiv:1211:5102 Relation LHeC-LHC

Simulated PDFs from LHeC are on LHAPDF (Partons from LHeC, MK, V.Radescu LHeC-Note-2013-002 PHY)

Higgs with HL-LHC

LHC 300 fb^{-1} at 14 TeV:

- Mass: <100 MeV (statistical)
- Coupling κ rel. precision*
  - Z, W, b, τ 10-15%
  - t, μ 3-2 σ observation
  - $\gamma\gamma$ and gg 5-11%

HL-LHC 3000 fb^{-1} at 14 TeV:

- Mass: << 50 MeV (statistical)
- Couplings κ rel. precision*
  - Z, W, b, τ, t, μ 2-10%
  - $\gamma\gamma$ and gg 2-5%

**Assuming sizeable (1/2) reduction of theory errors*

- "QCD scale" go to Higher order QCD computation ?
- gg "PDF" from LHC data ?

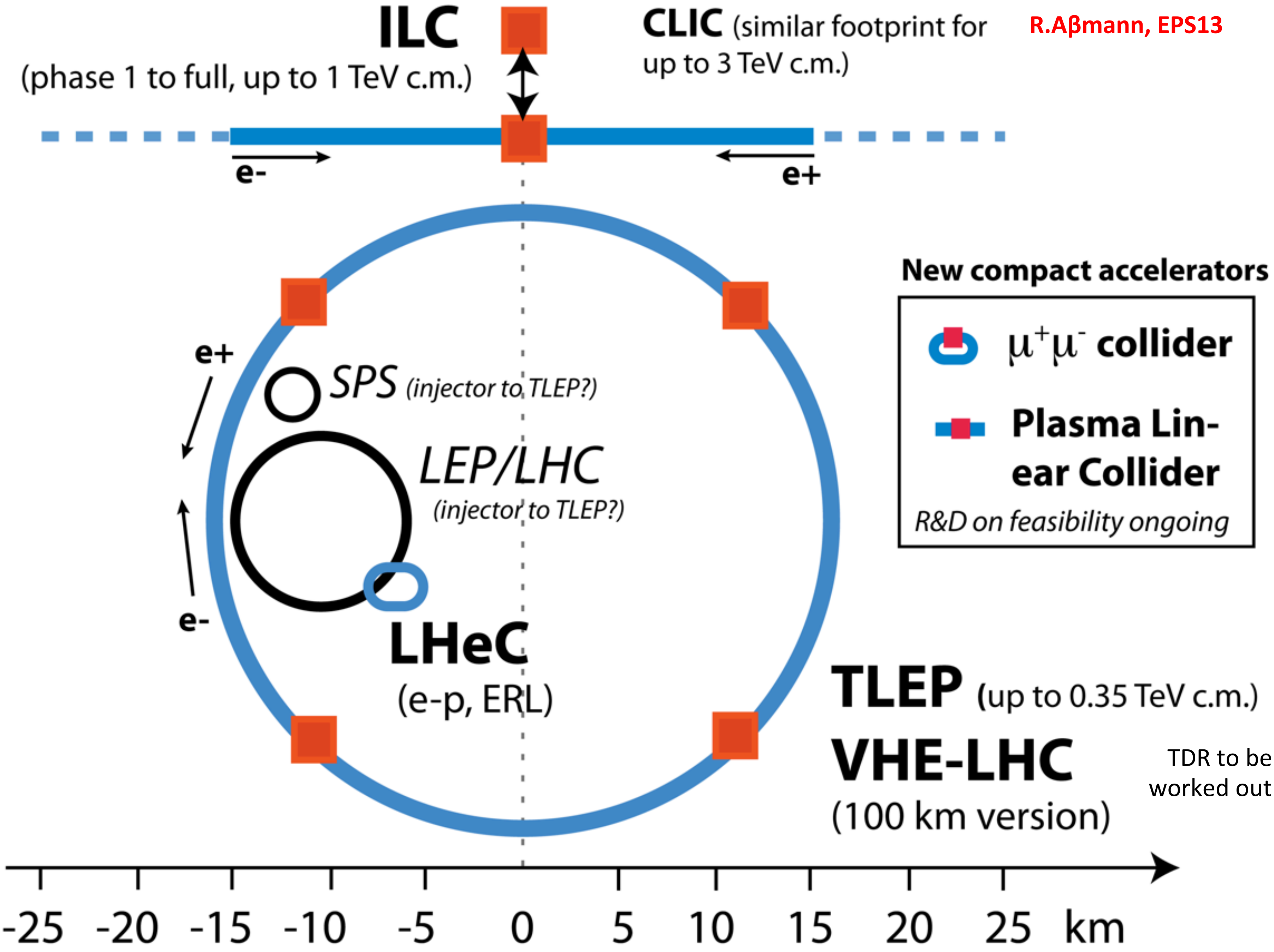
Mass Measurement:

Several exp./theory challenges to reach 50 MeV (e/γ/μ calibration E-scale, Interference, FSR, ..)

F.Cerutti, "Properties of the New Boson" EPS13 Stockholm

Higgs physics at the LHC is a long term challenge [di-H, CP, M, VV damping..]

Lepton collider options beyond LHC



September 2013

Structure of further work

Physics	Detector	Testfacility	Accelerator	Infrastructure
Higgs Top LHC-LHeC eA Low x Theory	Simulation Design Taggers Collaboration	Cavcryo module Magnets Source Optics Operation Coordination	Optimisation Optics IR Q1,2 Pipe+Vacuum Positrons Deuterons	Installation CE Resources Conferences Outreach Relations

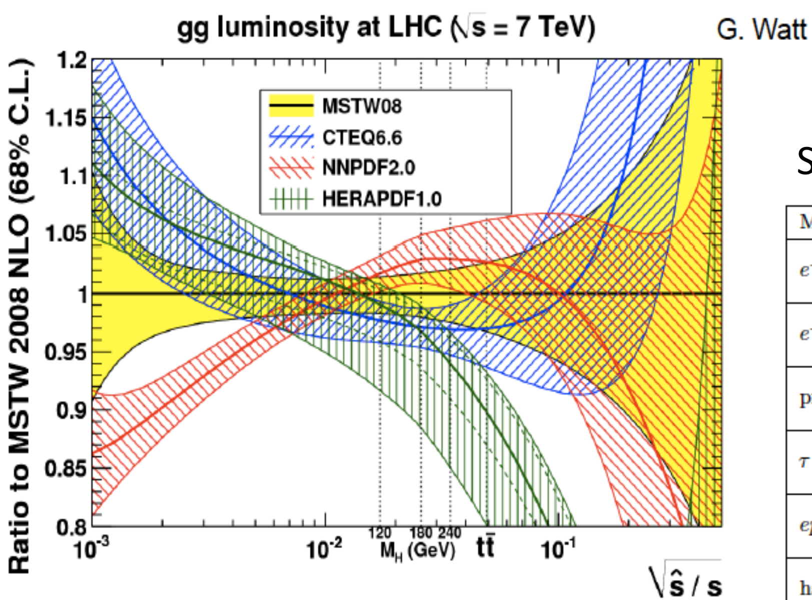
ERL Workshop at Novosibirsk

Presentations on the LHeC and on the ERL Testfacility by Oliver and Erk

January-October 2013

“Snowmass” 2013

arXiv:1310.5189



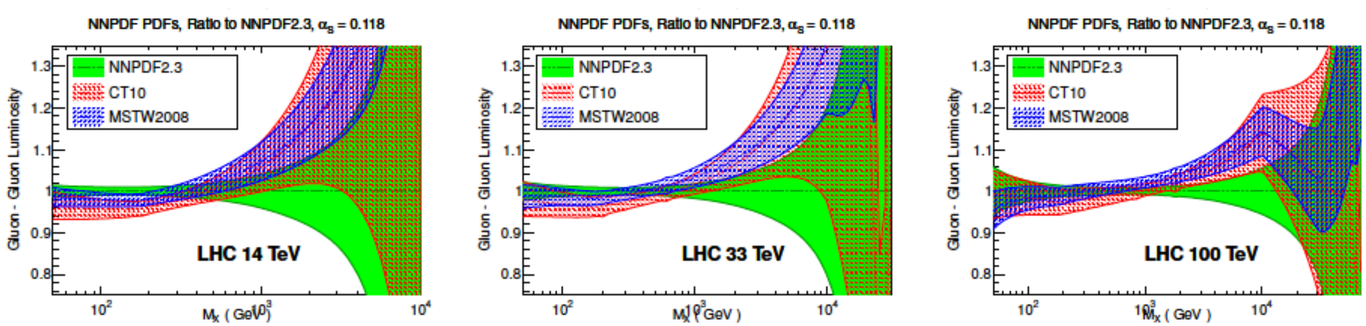
PDFs for QCD, H, BSM …

Important constraints from pp, but precision with ep! eA is unknown

Strong coupling constant to better than lattice precision

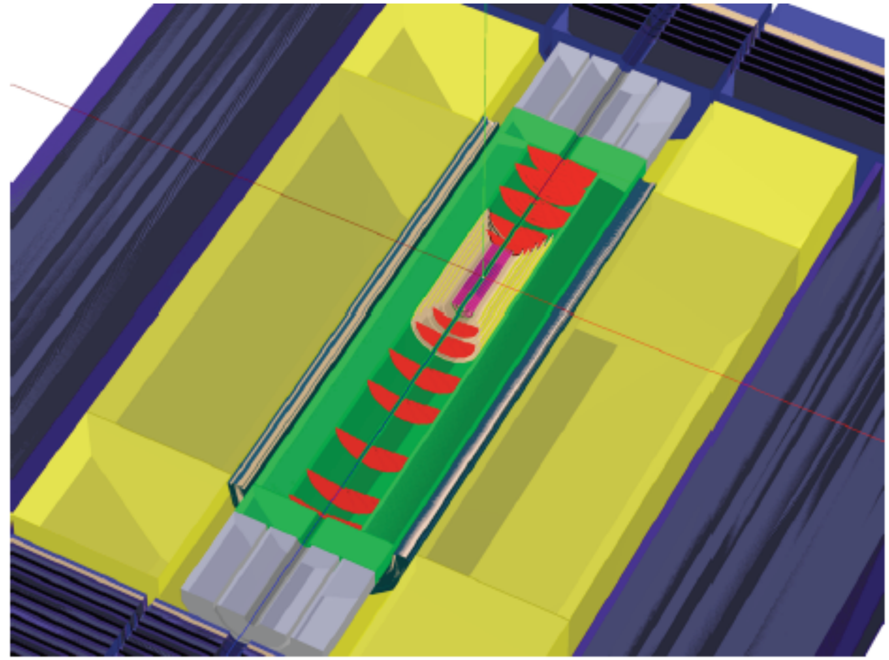
Method	Current relative precision	Future relative precision
e^+e^- evt shapes	expt $\sim 1\%$ (LEP) thry ~ 1–3% (NNLO+up to N^{3}LL, n.p. signif.) [27]	$< 1\%$ possible (ILC/TLEP) $\sim 1\%$ (control n.p. via Q^2-dep.)
e^+e^- jet rates	expt $\sim 2\%$ (LEP) thry $\sim 1\%$ (NNLO, n.p. moderate) [28]	$< 1\%$ possible (ILC/TLEP) $\sim 0.5\%$ (NLL missing)
precision EW	expt $\sim 3\%$ (R_Z, LEP) thry $\sim 0.5\%$ (N^{3}LO, n.p. small) [9, 29]	0.1% (TLEP [10]), 0.5% (ILC [11]) $\sim 0.3\%$ (N^{4}LO feasible, $\sim$ 10 yrs)
τ decays	expt $\sim 0.5\%$ (LEP, B-factories) thry $\sim 2\%$ (N^{3}LO, n.p. small) [8]	$< 0.2\%$ possible (ILC/TLEP) $\sim 1\%$ (N^{4}LO feasible, $\sim$ 10 yrs)
ep colliders	~ 1–2% (pdf fit dependent) [30, 31], (mostly theory, NNLO) [32, 33]	0.1% (LHeC + HERA [23]) $\sim 0.5\%$ (at least N^{3}LO required)
hadron colliders	$\sim 4\%$ (Tev. jets), $\sim 3\%$ (LHC $t\bar{t}$) (NLO jets, NNLO $t\bar{t}$, gluon uncert.) [17, 21, 34]	$< 1\%$ challenging (NNLO jets imminent [22])
lattice	$\sim 0.5\%$ (Wilson loops, correlators, ...) (limited by accuracy of pert. th.) [35–37]	$\sim 0.3\%$ ($\sim$ 5 yrs [38])

Gluon-gluon luminosity at the LHC, HE LHC and FCC



November 2013

mDetector Workshop at CERN



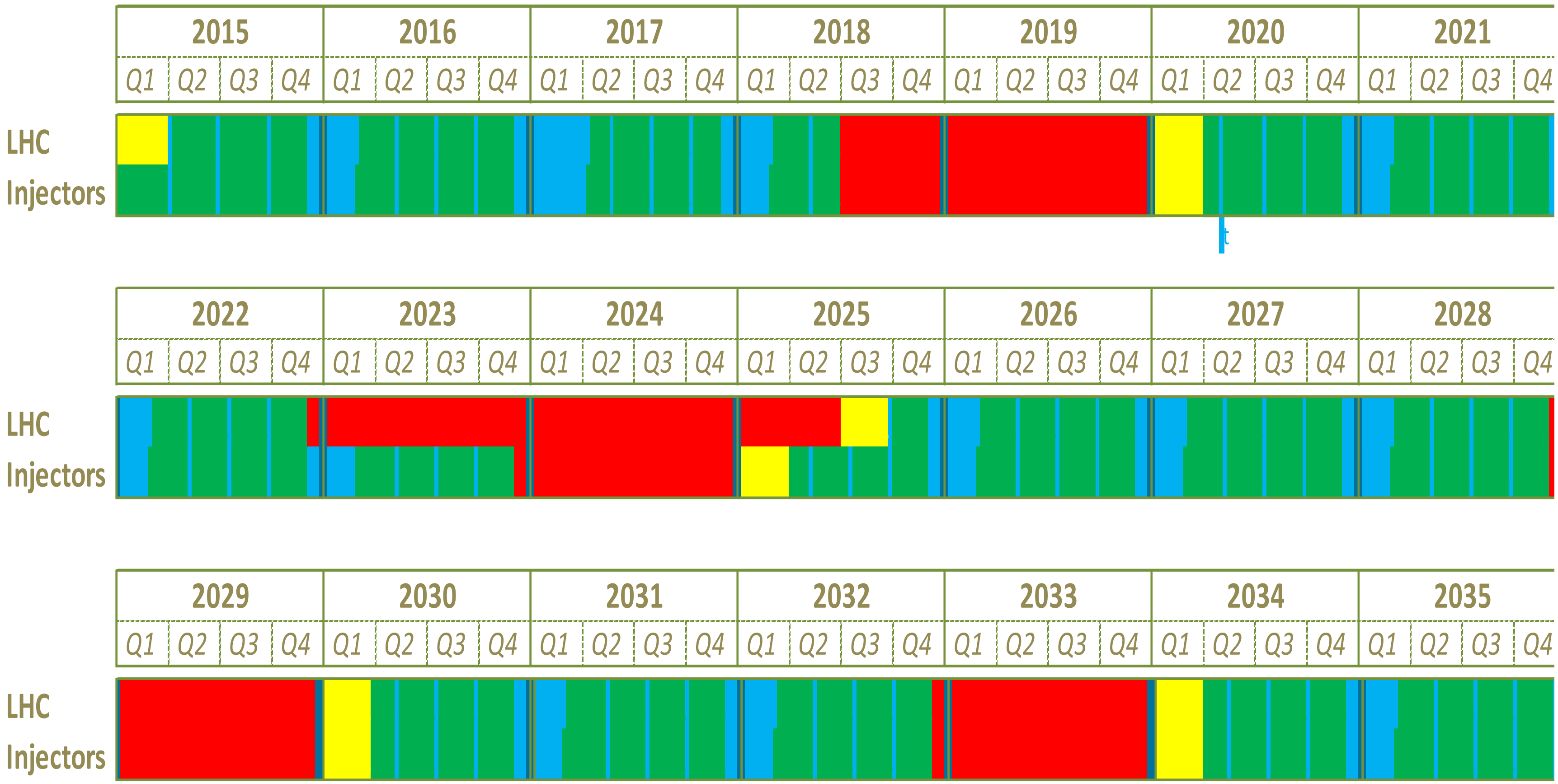
HL LHC optics – synchrotron radiation, detector dipole,
Masks and absorber - IR design
Beam pipe and forward/backward tracking acceptance near beam axis,
Detector performance for vertexing, particle flow, fwd jets
Solenoid position
Software framework for generation, simulation, reconstruction
Generators for ep and eA → **Realism in Design and Physics Studies (H)**

- A new phase in detector design using DD4hep started (pre-release software)
  ---- complete software simulation environment
- Identify / address critical items, discuss timeline for realisation

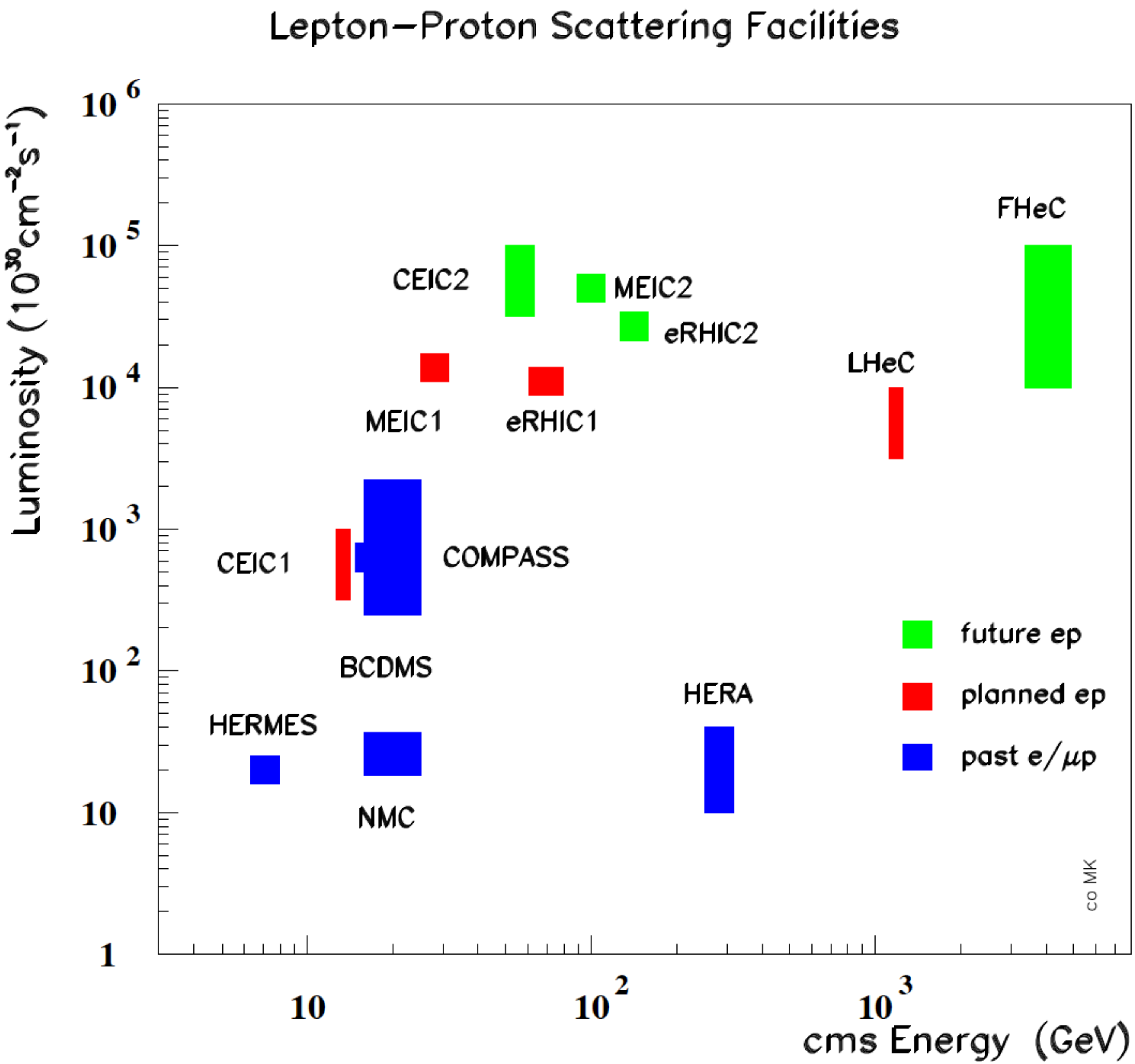
P.Kostka

November 2013

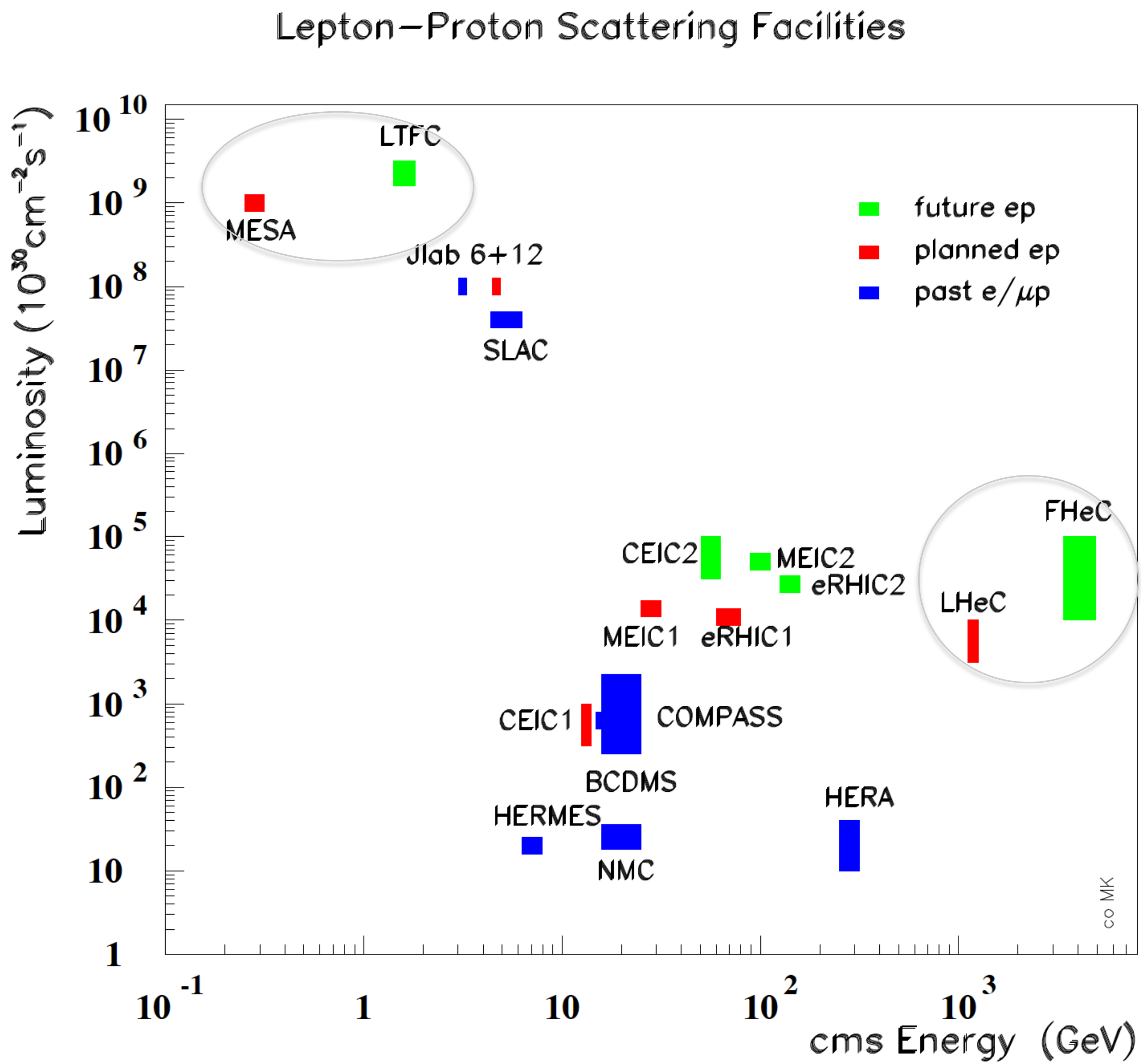
A long projected lifetime of the LHC



F.Bordry LHCC 11/2013



Lepton−Proton Scattering Facilities
Luminosity ($10^{30}cm^{-2}s^{-1}$)
cms Energy (GeV)
1
10
10^2
10^3
10^4
10^5
10^6
10
10^2
10^3
CEIC2
MEIC2
eRHIC2
FHeC
LHeC
MEIC1
eRHIC1
CEIC1
COMPASS
BCDMS
HERMES
NMC
HERA
future ep
planned ep
past e/μp
co MK


Lepton–Proton Scattering Facilities
Luminosity ($10^{30}cm^{-2}s^{-1}$)
cms Energy (GeV)
future ep
planned ep
past e/μp
LTFC
MESA
Jlab 6+12
SLAC
CEIC2
MEIC2
eRHIC2
MEIC1
eRHIC1
FHeC
LHeC
CEIC1
COMPASS
BCDMS
HERMES
NMC
HERA
co MK

December 2013

International Advisory Committee

*)

Guido Altarelli (Rome)
Sergio Bertolucci (CERN)
Frederick Bordry (CERN)
Angela Bracco (Milano)
Hesheng Chen (IHEP Beijing)
Andrew Hutton (Jefferson Lab)
Young-Kee Kim (Chicago and Fermilab)
Victor A. Matveev (JINR Dubna)
Shin-Ichi Kurokawa (Tsukuba)
Leandro Nisati (Rome)
Leonid Rivkin (EPF Lausanne)
Herwig Schopper (CERN) - Chair
Jürgen Schukraft (CERN)
Achille Stocchi (LAL Orsay)

The IAC was invited in 12/13 by the DG with the following

Mandate 2014-2017

Advice to the LHeC Coordination Group and the CERN directorate by following the development of options of an ep/eA collider at the LHC and at FCC, especially with:

Provision of scientific and technical direction for the physics potential of the ep/eA collider, both at LHC and at FCC, as a function of the machine parameters and of a realistic detector design, as well as for the design and possible approval of an ERL test facility at CERN.

Assistance in building the international case for the accelerator and detector developments as well as guidance to the resource, infrastructure and science policy aspects of the ep/eA collider.

*) IAC Composition early January 2014

December 2013

LHeC Coordination Group

LCG (2014-2017) *)

Nestor Armesto
Oliver Brüning
Stefano Forte
Andrea Gaddi
Bruce Mellado
Max Klein
Peter Kostka
Daniel Schulte
Frank Zimmermann

Directors (ex-officio)
Sergio Bertolucci, Frederick Bordry

The coordination group was invited end of December 2014 by the CERN directorate with the following mandate (2014-2017)

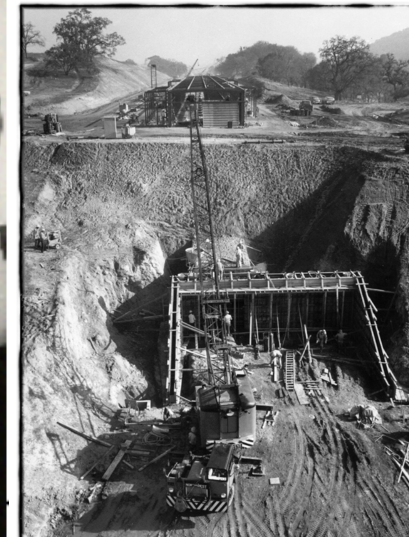
The group has the task to coordinate the study of the scientific potential and possible technical realisation of an ep/eA collider and the associated detectors at CERN, with the LHC and the FCC, over the next four years. It also should coordinate the design of an ERL test facility at CERN as part of the preparations for a larger energy electron accelerator employing ERL techniques.

The group will cooperate with CERN and an International Advisory Committee, chaired by the emeritus DG of CERN, Professor Herwig Schopper, who also advises the CERN directorate. The Coordination Group is asked to represent the ep/eA collider development towards CERN, its committees and the international community. The currently tentative composition is listed *left*. CERN has asked Max Klein to chair and Oliver Brüning to co-chair this activity

*) LCG Composition early January 14

can one build a 2-3-km long linac?






it has been done before

Courtesy F.Zimmermann

COMING SOON

SITE UNDER CONSTRUCTION

A New Web Page and Information

This comes tonight

Workshop Information

Monday: Plenary opening – Photograph – Lunch – Parallel Sessions – Dinner (19.30)

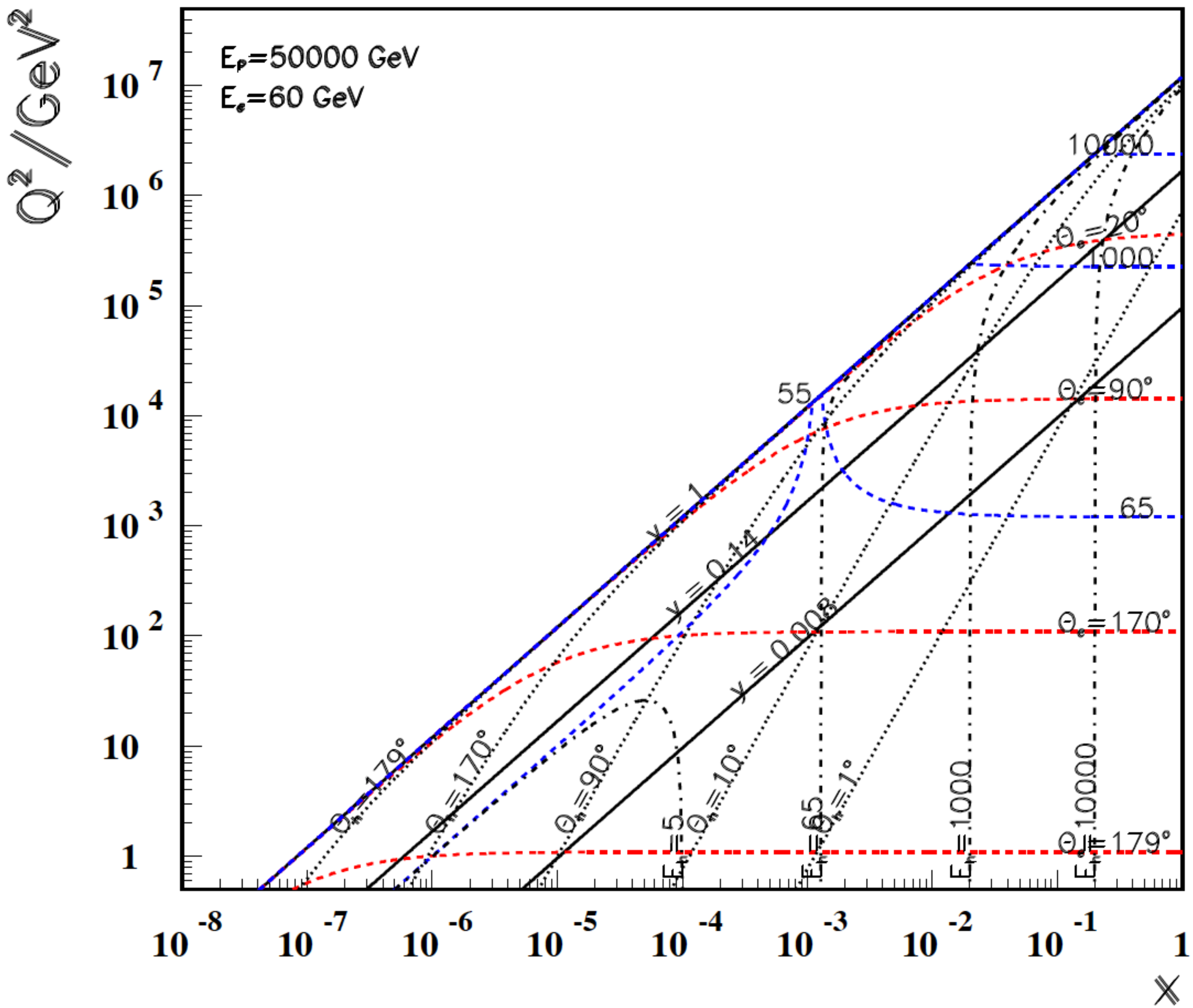
Tuesday: Parallel sessions – Lunch – Summaries of Physics/Det and Acc/TF – conclusion

91 – 89 – 86 – 106 – 103

Welcome to the Workshop

backup

Questions on the FCC – ep



Isn't E_p=50 TeV too high for acceptance with a lower energy electron beam (60-200 GeV) ?

Surprisingly not.

Low x: $Q^2_{min} \sim E_e^2$

Large x: needs very fwd tracking (to 1°)

FHeC comes with HERA and after LHeC

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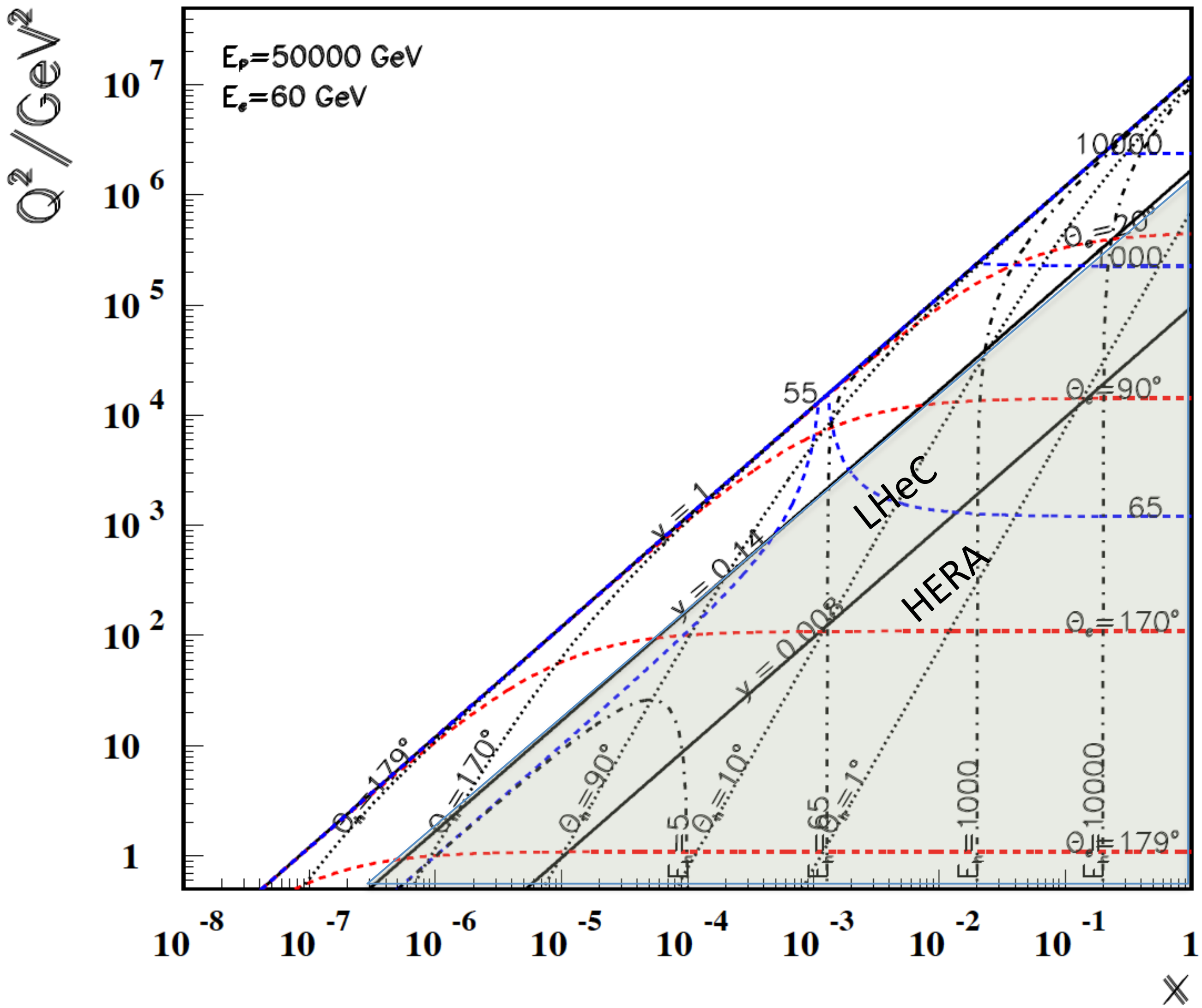

Isn't E_p=50 TeV too high for acceptance with a lower energy electron beam (60-200 GeV) ?

Surprisingly not.

Low x: Q^2_{min} ~ E_e^2 →
For low x keep Ee at ~ 60 GeV

Large x: needs very fwd tracking (to 1°)

FHeC comes with HERA and after LHeC

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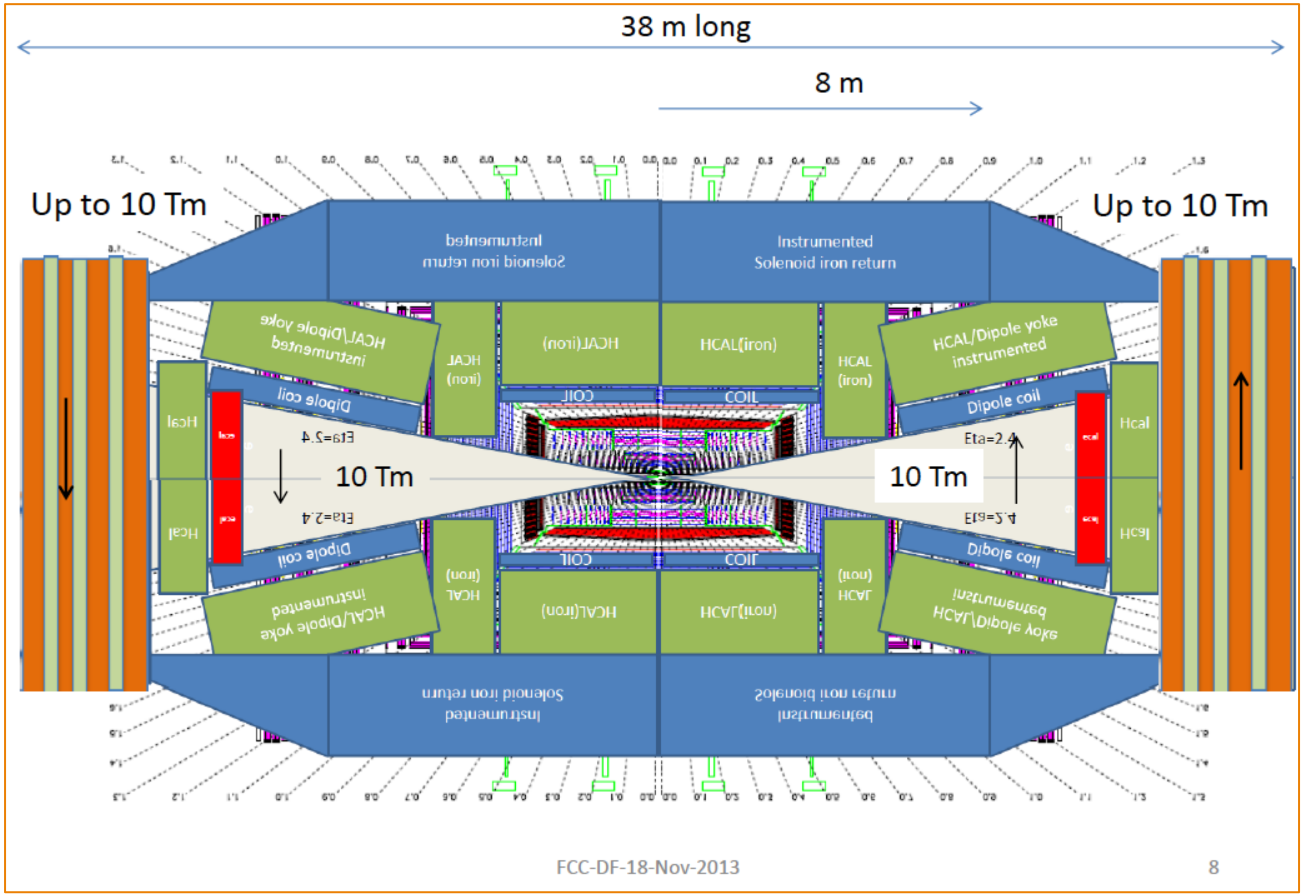

How would a detector look like?

Perhaps sth between the LHeC and the FCC detector

FHC: From D.Fournier with F.Gianotti, L.Pontecorvo, H.TenKate Nov13 FHC Meeting at CERN
LHeC: From Conceptual Design Report

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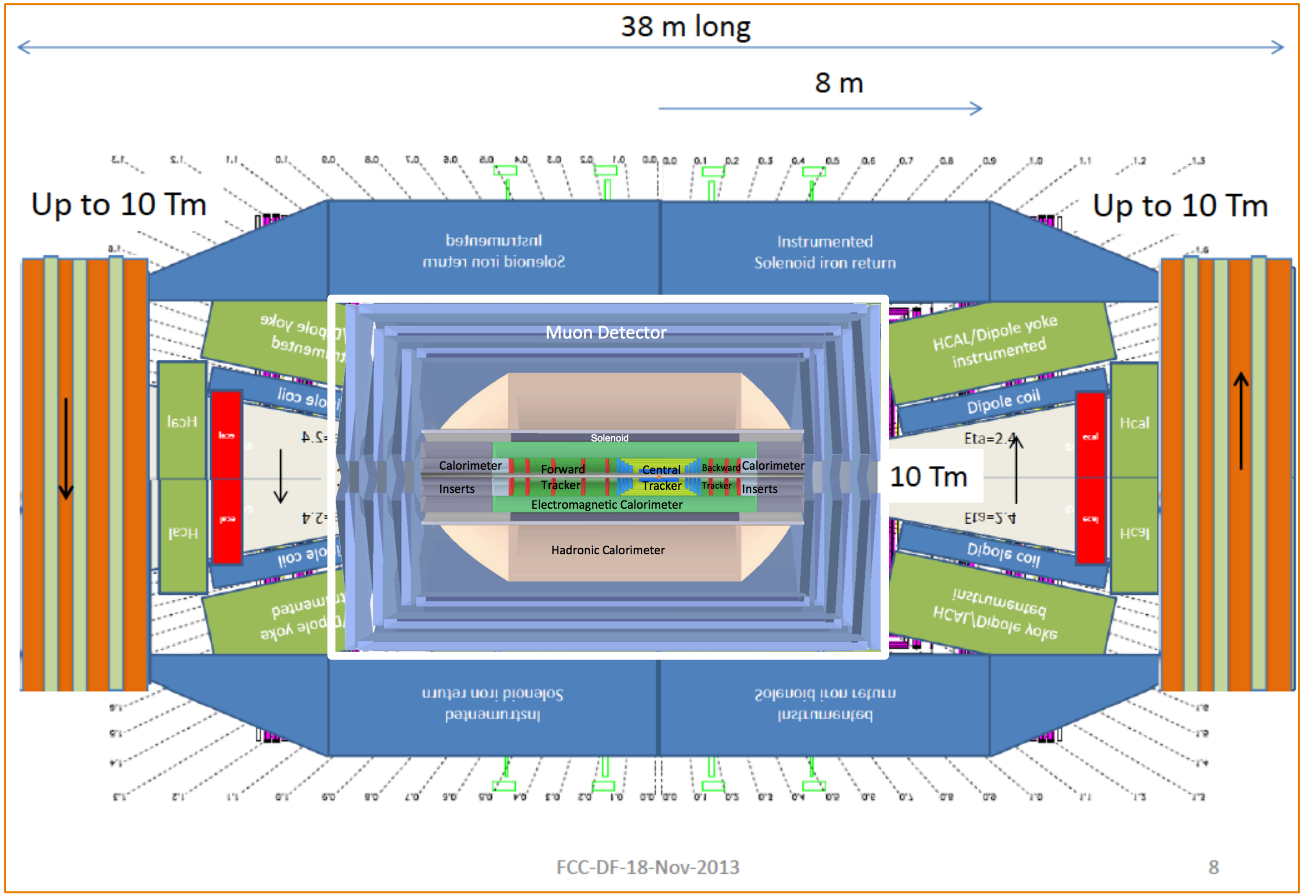

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FEC- future electron-positron colliders

LINEAR COLLIDER COLLABORATION

~~My~~ Juan Fuster's summary of the summary

Sense títol, 2009 **El Roto, Andrés Rábago García**

An "expert" has advised me that only the biggest and most aggressive will survive

Plenary ECFA talk by Juan Fuster, November 2013 at CERN, on the Linear Collider

Tentative Parameters for FHeC (RR)

collider parameters	$e^{\pm}$ scenarios			protons
species	$e^{\pm}$	$e^{\pm}$	$e^{\pm}$	p
beam energy [GeV]	**60**	**120**	**250**	**50000**
bunch spacing [μs]	0.125	2	33	0.125 to 33
bunch intensity [10^{11}]	3.8	3.7	3.3	3.0
beam current [mA]	477	29.8	1.6	384 (max)
rms bunch length [cm]	0.25	0.21	0.18	2
rms emittance [nm]	6.0, 3.0	7.5, 3.75	4, 2	0.06, 0.03
$\beta_{x,y}$*[mm]	5.0, 2.5	4.0, 2.0	9.3, 4.5	500, 250
$\sigma_{x,y}$* [μm]	5.5, 2.7			
b-b parameter ξ	**0.13**	0.050	0.056	0.017
hourglass reduction	**0.42**	**0.36**	0.68	
CM energy [TeV]	3.5	4.9	7.1	
luminosity[10^{34}cm^{-2}s^{-1}]	**21**	**1.2**	**0.07**	

F.Zimmermann at Beijing 16.12.13

Design Parameters

parameter [unit]	LHeC	
species	e	p, $^{208}Pb^{82+}$
beam energy (/nucleon) [GeV]	60	7000, 2760
bunch spacing [ns]	25, 100	25, 100
bunch intensity (nucleon) [10^{10}]	0.1 (0.2), 0.4	17 (22), 2.5
beam current [mA]	6.4 (12.8)	860 (1110), 6
rms bunch length [mm]	0.6	75.5
polarization [%]	90 (e^+ none)	none, none
normalized rms emittance [μm]	50	3.75 (2.0), 1.5
geometric rms emittance [nm]	0.43	0.50 (0.31)
IP beta function $\beta^*_{x,y}$ [m]	0.12 (0.032)	0.1 (0.05)
IP spot size [μm]	7.2 (3.7)	7.2 (3.7)
synchrotron tune Q_s	—	1.9×10^{-3}
hadron beam-beam parameter	0.0001 (0.0002)	
lepton disruption parameter D	6 (30)	
crossing angle	0 (detector-integrated dipole)	
hourglass reduction factor H_{hg}	0.91 (0.67)	
pinch enhancement factor H_D	1.35 (0.3 for e^+)	
CM energy [TeV]	1.3, 0.81	
luminosity / nucleon [10^{33} cm^{-2}s^{-1}]	1 (10), 0.2	

arXiv:1211:5102

Designed for synchronous ep and pp operation during the HL-LHC phase.